

# Human Exploration Update to the NAC HEO Committee

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Human Exploration and Operations Mission Directorate

**December 2, 2015**



- **Summary from last meeting**
- **Recent progress**
  - ISS including CRS status
  - Commercial Crew Program
  - Exploration Systems Program
  - Asteroid Redirect Mission
- **Journey to Mars architecture planning**
  - J2M documents
  - Evolvable Mars Campaign FY16 studies
  - Proving Ground goals and objectives –  
lead in to next presentation

# Summary Observations



- **NASA's long-term human spaceflight objective is to “extend human presence into the solar system and to the surface of Mars” (2014 NASA Strategic Plan)**
- **Sustainability is the central idea in NASA's approach, and why we implement the journey to Mars with a pioneering approach**
- **A sustained program requires:**
  - Resilient architectures (the Evolvable Mars Campaign vs a DRM)
  - Robust and evolvable access to space (SLS & Orion)
  - Safe and productive long-duration human spaceflight (ISS HRP and deep space habitation)
  - In-space transportation, AR&D for cargo and crew missions (ARM/SEP and SEP/Chem hybrid concepts)
  - Knowledge of Mars and access to Mars surface (current and future robotic Mars missions)
  - Standards that allow hardware from a variety of sources (commercial/International)  
Docking standard—Life support systems
- **All of these are features of NASA's current programs and investment strategy – our current programs make sense in this strategic context**
- **We progress at the rate funding, technologies, and partnerships allow**







# Recent Progress



- **Passed the halfway point in the One-Year Crew mission and the 15 year mark for ISS continuous human presence**
- **Selected launch vehicle for TDRS-M: Atlas V 401 for October 2017**
- **Issued contracts for new small launch vehicle services**
- **Commercial crew milestones on track for 2016**
  - Launch pads for both SpaceX and Boeing
  - CDR for SpaceX
  - Structural test article for Boeing
  - Alternate requirements acceptance for both
- **Completed CDR for SLS and PDR for Orion; CDR for Orion and GSDO underway**
  - Hardware for EM-1 well underway (SLS/Orion/GSDO)
- **Announced time window for applications for next astronaut class (Dec – Feb)**
- **Awarded SACOM contract to achieve synergy in technical services between MAF & SSC**
- **Request for Proposal released for industry early design phase studies to leverage existing commercially available spacecraft bus capabilities for ARM advanced SEP bus build**

# Venture Class Launch Services Awardees



|  |  |  |
|--|--|--|
|   <p><b>Firefly<br/>Alpha 1.0</b> <b>\$5.5M</b></p> <ul style="list-style-type: none"> <li>• ~75 feet tall</li> <li>• ~1 meter fairing</li> <li>• 2 Stage liquid propulsion</li> <li>• Composite Structure</li> <li>• ~150 – 400kg to LEO</li> <li>• Actively seeking additional investment funding</li> </ul> <p><i>VCLS Launch targeting<br/>March 2018</i></p> |   <p><b>Rocket Lab<br/>Electron</b> <b>\$6.9M</b></p> <ul style="list-style-type: none"> <li>• ~60 feet tall</li> <li>• ~1 meter fairing</li> <li>• 2 Stage liquid propulsion</li> <li>• Composite Structure</li> <li>• ~100 – 250kg to LEO</li> <li>• Development is fully funded</li> </ul> <p><i>VCLS Launch targeting<br/>April 2017</i></p> |   <p><b>Virgin<br/>LauncherOne</b> <b>\$4.7M</b></p> <ul style="list-style-type: none"> <li>• ~65 feet long</li> <li>• ~1 meter fairing</li> <li>• 2 Stage liquid propulsion</li> <li>• Carrier aircraft launched</li> <li>• Composite Structure</li> <li>• ~150 – 350kg to LEO</li> <li>• Development is fully funded</li> </ul> <p><i>VCLS Launch targeting<br/>late 2017</i></p> |
|--|--|--|

# ISS One-Year Mission



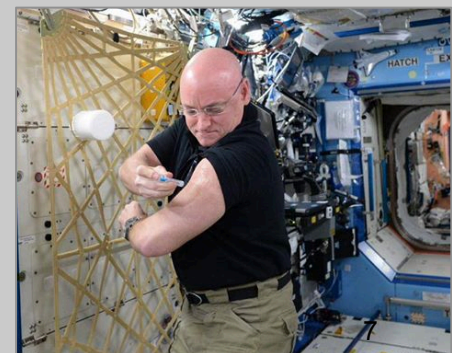
- **Completed First 6-months of One-year Mission**
  - Mission Progressing Well and Benefits of Collaborative Work Using Joint Capabilities and Resources are Being Realized
  - Astronaut Scott Kelly set the record for the longest duration American space mission on day 215
- **All Studies in the US-Russian Joint Research Plan have Been Implemented**
  - Physical and Functional Performance Assessments
  - Behavioral Health Studies
  - Ocular Health Monitoring and Changes
  - Metabolic and Immune System Studies
  - Microbial Population Changes
  - Long-Duration Mission Human Factors Studies
- **US/Russian Fluids Shift Experiment**
  - Most complex biomedical experiment implemented on ISS
  - Experiment could only be undertaken using both US and Russian hardware, subjects, and crew time
  - Studies body fluids redistribution during long-duration missions that may cause the visual and intracranial pressure changes that occur in crewmembers



# Twins Study



- **Twins Study (Scott and Mark Kelly)**
  - Sample collection is preceding well
  - Scott and Mark received influenza vaccination to test differential immune system response
- **Objective is to Begin Examining Next Generation Genomics Solutions to Mitigating Crew Health and Performance Risks**
  - Personalized countermeasures approaches
- **Twins Study National Research Team will Examine**
  - Genome, telomeres, epigenome
  - Transcriptome and epitranscriptome
  - Proteome, Metabolome, Microbiome
  - Physiology and Cognition
- **Significant Privacy and Ethics Issues**
  - NASA is developing new genomics policy (modeled after NIH policy) that addresses informed consent, data privacy approaches, and genetic counseling on consequences of discovery (individual, family)



# ISS Technology Demonstration Plan



| Capability Gap                                       | FY14     | FY15           | FY16                   | FY17            | FY18                  | FY19                     | FY20       | FY21 | FY22                  | FY23 | FY24 | FY25 | FY26 | FY27 | FY28 |
|--|----------|----------------|------------------------|-----------------|-----------------------|--------------------------|------------|------|-----------------------|------|------|------|------|------|------|
| <b>ECLSS</b>   |          |                |                        |                 |                       |                          |            |      |                       |      |      |      |      |      |      |
| Reliable CO2 Removal + ppCO2<2 mmHg                  | ▲ CDRA-5 |                | ▲ LDST                 |                 | Next Gen 4BMF         | ▲                        |            | ▲    | Alt. Tech. Demo       |      |      |      |      |      |      |
| Smaller, simpler O2 Gen                              |          |                |                        |                 | OGA Upgrades          | ▲                        |            |      |                       |      |      |      |      |      |      |
| High pressure O2 (3000 psi) for EVA & medical use    |          |                |                        |                 | HPOGA or Concentrator | ▲                        |            |      |                       |      |      |      |      |      |      |
| Reliable urine processing =85% recovery              |          |                | ▲ alt pt               | ▲ PCPA upgrade  |                       | ▲ next gen UPA           |            |      |                       |      |      |      |      |      |      |
| Reliable processing w/ reduced expendables           |          |                | MFB & reactor upgrades | ▲               |                       | Alt. architecture        | ▲          |      |                       |      |      |      |      |      |      |
| Common biocide with on orbit replenishment           |          |                | Dosing demo            | ▲               |                       |                          |            |      |                       |      |      |      |      |      |      |
| Compact waste & trash mngmt, stable, 90% water recov |          |                |                        |                 | UWMS                  | ▲                        |            |      | HMC                   | ▲    |      |      |      |      |      |
| Additional O2 recovery from CO2 >75%                 |          |                |                        |                 |                       |                          |            |      | >75% recovery         | ▲    |      |      |      |      |      |
| >90% recovery of water from urine brine              |          |                |                        | ▲               | demo candidates       |                          |            |      |                       |      |      |      |      |      |      |
| Condensing HX robust, inert, anti-microbial          |          |                |                        |                 |                       |                          |            |      |                       |      |      |      |      |      |      |
| 10:1 volume reduction logistical & clothing          |          | ▲ adv clothing |                        | RFID Logistics  | ▲                     |                          |            |      | laundry/sanitation    | ▲    |      |      |      |      |      |
| <b>Environmental Monitoring</b>                      |          |                |                        |                 |                       |                          |            |      |                       |      |      |      |      |      |      |
| Trace Gas (on orbit, no grab sample return)          | ▲ AQM    |                |                        |                 | ▲ SAM                 |                          |            |      |                       |      |      |      |      |      |      |
| Targeted Gases (fire products, NH3, hydrazine)       |          | ▲ MGM          |                        |                 |                       | ▲ CPM                    | on saffire |      |                       |      |      |      |      |      |      |
| Water (individual compounds)                         |          |                | ▲ suite                |                 |                       |                          |            |      |                       |      |      |      |      |      |      |
| Microbial (ID & qty species)                         |          |                |                        | COTS            |                       | Expl PCR                 | ▲          |      |                       |      |      |      |      |      |      |
| Major Constituents (small, no maintenance)           |          |                |                        |                 | ▲ SAM                 |                          | MPAM       | ▲    |                       |      |      |      |      |      |      |
| Particulates   |          |                | ▲                      | aerosol sampler |                       | ▲ Monitor                |            |      |                       |      |      |      |      |      |      |
| Acoustic (automated, alerting, no crew time)         |          |                |                        |                 | ▲ tech demo           | ▲ operational            |            |      |                       |      |      |      |      |      |      |
| <b>EVA</b>   |          |                |                        |                 |                       |                          |            |      |                       |      |      |      |      |      |      |
| Exploration PLSS/Microgravity Suit                   |          |                |                        |                 |                       |                          |            |      | ▲ Deploy on ISS       |      |      |      |      |      |      |
| <b>Fire Safety and Response</b>                      |          |                |                        |                 |                       |                          |            |      |                       |      |      |      |      |      |      |
| Emergency Mask (single cartridge)                    | ▲ dual   |                |                        |                 | ▲ single              |                          |            |      |                       |      |      |      |      |      |      |
| Contingency Air Monitor (overlap with targeted gas)  |          |                |                        |                 |                       | ▲                        |            |      | Demo in Saffire IV-VI |      |      |      |      |      |      |
| Smoke Eater  |          |                |                        |                 |                       | ▲                        |            |      | Demo in Saffire IV-VI |      |      |      |      |      |      |
| Water Mist PFE                                       |          |                | ▲ ISS size             |                 | ▲                     | Expl. Size, lightwt tank |            |      |                       |      |      |      |      |      |      |
| Large fire behavior in ug                            |          |                | ▲ Saffire-I-III        |                 | ▲                     | Saffire IV-VI            |            |      |                       |      |      |      |      |      |      |

11-30-15



no committed funding



some \$, but insufficient funding for ISS demo



sufficient funding to ISS demo



Funded ISS demo



Proposed ISS demo (not yet funded)

# ISS Technology Demonstration Plan



| Capability Gap  | FY14 | FY15                 | FY16            | FY17          | FY18   | FY19                          | FY20                            | FY21                      | FY22            | FY23 | FY24 | FY25 | FY26 | FY27 | FY28 |
|---|------|----------------------|-----------------|---------------|--------|-------------------------------|---------------------------------|---------------------------|-----------------|------|------|------|------|------|------|
| <b>ECLSS</b>  |      |                      |                 |               |        |                               |                                 |                           |                 |      |      |      |      |      |      |
| <b>Crew Health &amp; Performance Technologies</b>   |      |                      |                 |               |        |                               |                                 |                           |                 |      |      |      |      |      |      |
| Exercise Equipment  |      |                      | ▲ MED-2 (Orion) |               |        |                               | ▲                               | Exploration device        |                 |      |      |      |      |      |      |
| Medical Equipment   |      |                      |                 |               | ▲      | ESMD                          |                                 |                           |                 |      |      |      |      |      |      |
| Food System   |      |                      |                 |               |        |                               |                                 | ▲                         | Adv food system |      |      |      |      |      |      |
| <b>Thermal (including Cryo)</b>   |      |                      |                 |               |        |                               |                                 |                           |                 |      |      |      |      |      |      |
| Zero Boil Off Cryo  |      |                      | ▲               | ZBOT Ph 1     | ▲      | ZBOT Ph 2                     |                                 | ▲                         | ZBOT Ph 3       |      |      |      |      |      |      |
| Phase Change Material   |      |                      | ▲               | wax           | ▲      | water                         |                                 |                           |                 |      |      |      |      |      |      |
| Variable Heat Rejection radiators, single loop fluids   |      |                      |                 |               |        | ▲                             |                                 |                           |                 |      |      |      |      |      |      |
| <b>Power &amp; Energy Storage</b>   |      |                      |                 |               |        |                               |                                 |                           |                 |      |      |      |      |      |      |
| Solar arrays  |      |                      |                 | ▲ ROSA        |        |                               | ▲                               | 30 kW Common agency array |                 |      |      |      |      |      |      |
| Energy Storage  |      |                      |                 | ▲ Li ion batt | ▲      | Regen fuel cell               |                                 |                           |                 |      |      |      |      |      |      |
| <b>Comm &amp; Navigation</b>  |      |                      |                 |               |        |                               |                                 |                           |                 |      |      |      |      |      |      |
| High speed comm/internetworking   | ▲    | DTN & OPALS, SCAN TB |                 |               | ▲      | ISS terminal                  |                                 | ▲                         | TDRS upgrades   |      |      |      |      |      |      |
| Position, navigation, and timing  |      |                      | ▲               | NICER/SEXTANT |        |                               |                                 |                           |                 |      |      |      |      |      |      |
| <b>Structures &amp; Materials</b>   |      |                      |                 |               |        |                               |                                 |                           |                 |      |      |      |      |      |      |
| Materials/In-space manufacturing  |      | ▲                    | 3D pri          | ▲             | manuf. | ▲                             | mtls reuse                      | ▲                         | "fab lab"       |      |      |      |      |      |      |
| Structures & Health Monitoring  |      |                      |                 | ▲             | BEAM   |                               |                                 |                           |                 |      |      |      |      |      |      |
| Radiation Monitoring & Shielding  |      | ▲                    | REM             | ▲             | FNS    |                               |                                 |                           |                 |      |      |      |      |      |      |
| <b>ISRU (trash processing, resource prospecting, in-situ manufacturing) Plans under construction.</b> |      |                      |                 |               |        |                               |                                 |                           |                 |      |      |      |      |      |      |
| Autonomous Operations   |      | ▲                    | TOCA            |               | ▲      | AMO EXPRES                    | ▲                               | ISS crew autonomy 2.0     |                 |      |      |      |      |      |      |
| Automated Rendezvous & Docking  |      |                      |                 | ▲             | RAVEN  |                               |                                 |                           |                 |      |      |      |      |      |      |
| <b>Robotics</b>   |      |                      |                 |               |        |                               |                                 |                           |                 |      |      |      |      |      |      |
| Robotic refueling   |      |                      | ▲               | RRM2          |        | ▲                             | RRM3 (includes cryo mass gauge) |                           |                 |      |      |      |      |      |      |
| Free flyer robots (IVA & EVA)   |      |                      | ▲               | IVA           |        | ▲                             | EVA                             |                           |                 |      |      |      |      |      |      |
| Human assist robots   |      | ▲                    | Robonaut        |               | ▲      | Robotic Caretaker             |                                 |                           |                 |      |      |      |      |      |      |
| Telerobotics  |      | ▲                    |                 |               |        |                               |                                 |                           |                 |      |      |      |      |      |      |
| <b>Entry, Descent, Landing</b>  |      |                      |                 |               |        |                               |                                 |                           |                 |      |      |      |      |      |      |
|   |      |                      | ▲               | RED-dar       | ▲      | Atmosphere re-entry deployers |                                 |                           |                 |      |      |      |      |      |      |



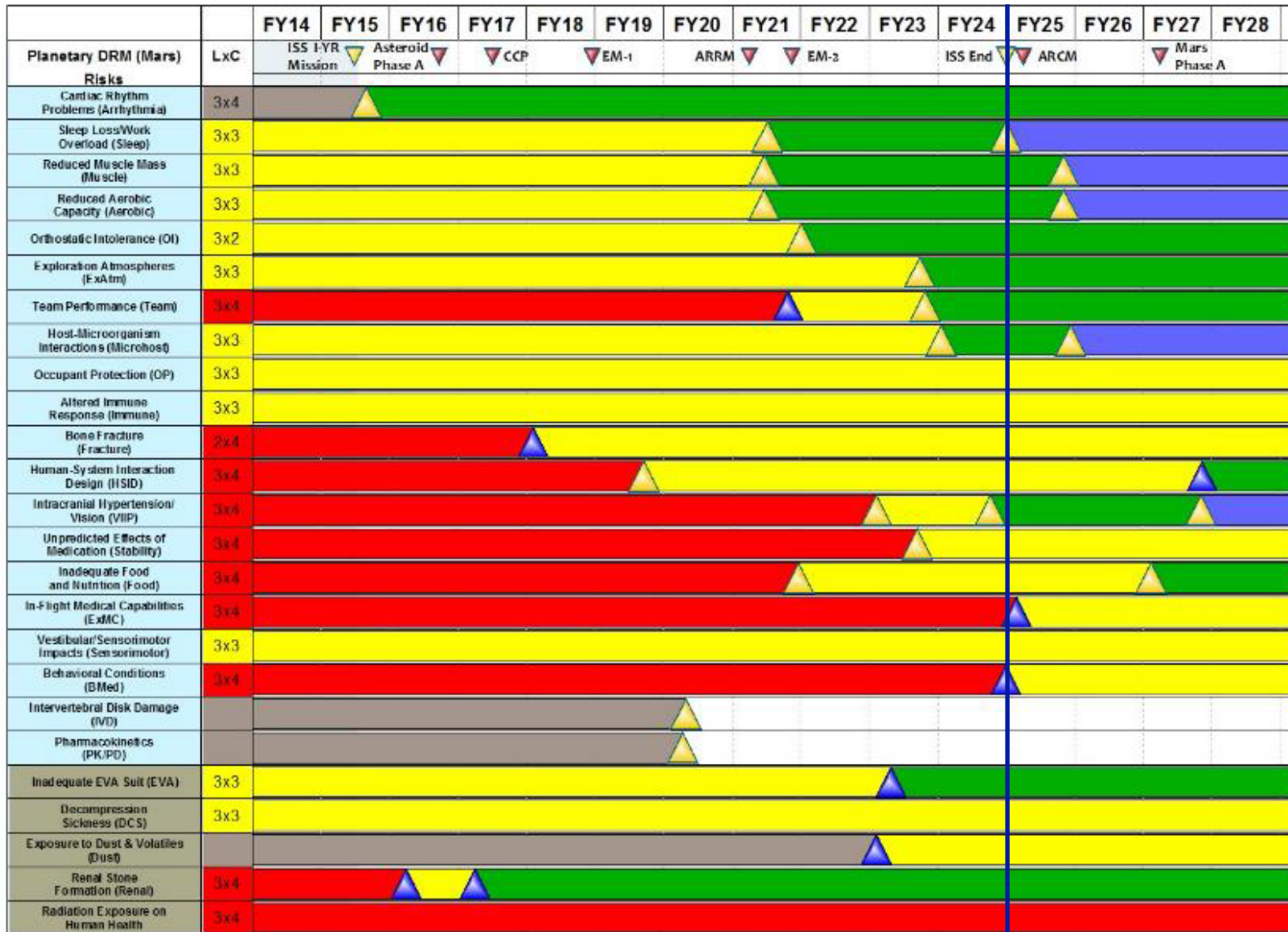
no committed funding  
 some \$, but insufficient funding for ISS demo  
 sufficient funding to ISS demo



Funded ISS demo  
 Proposed ISS demo (not yet funded)

11-30-15

# HRP Integrated Path to Risk Reduction



- Uncontrolled
- Partially Controlled
- Controlled
- Optimized
- Insufficient Data

- Assumptions:**
- 450 crew hrs/ Increment pair
  - 3 crew/ Increment pair
  - 6 month missions

Updated  
6/10/15

■ ISS Required ■ ISS Not Required

▲ Milestones Requires ISS ◆ Milestone Shift

Total = 25 risks require research

# OA-4 (Orb-4) Mission Status



- **Mission Planning**

- Orbital has contracted with United Launch Alliance (ULA) for an Atlas V launch of Cygnus
- First use of Atlas V401 with the Cygnus spacecraft
- Cargo Integration Review (CIR) was conducted on 7/29/15
- Safety Review Panel (SRP) TIMs on 8/5/15 and 9/15/15
- Chief Engineer Readiness Review was completed on 9/1/15
- ISS FRR for Orb-3 completed 11/16

- **Pressurized Cargo complement**

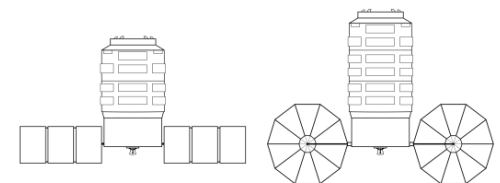
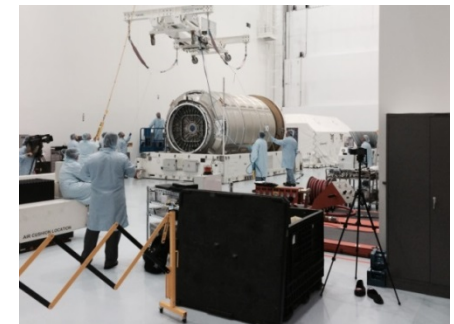
- NASA delivered ISS cargo manifest in June
- Planned Upmass : 7,730 pounds

- **Cygnus Status**

- First enhanced Cygnus with a longer Pressurized Cargo Module (PCM) and lightweight solar arrays
- Service Module (SM) will accommodate changes to the TriDAR/ LIDAR configuration
- PCM completed FE1410 testing at the Cape on 8/20/15
- SM completed Final Integrated Systems Test (FIST) and shipped to Cape on 10/15/15

- **Atlas V 401**

- Payload Adapter has been manufactured and is ready for integration
- Booster stacked and prepped for Dec 3 launch

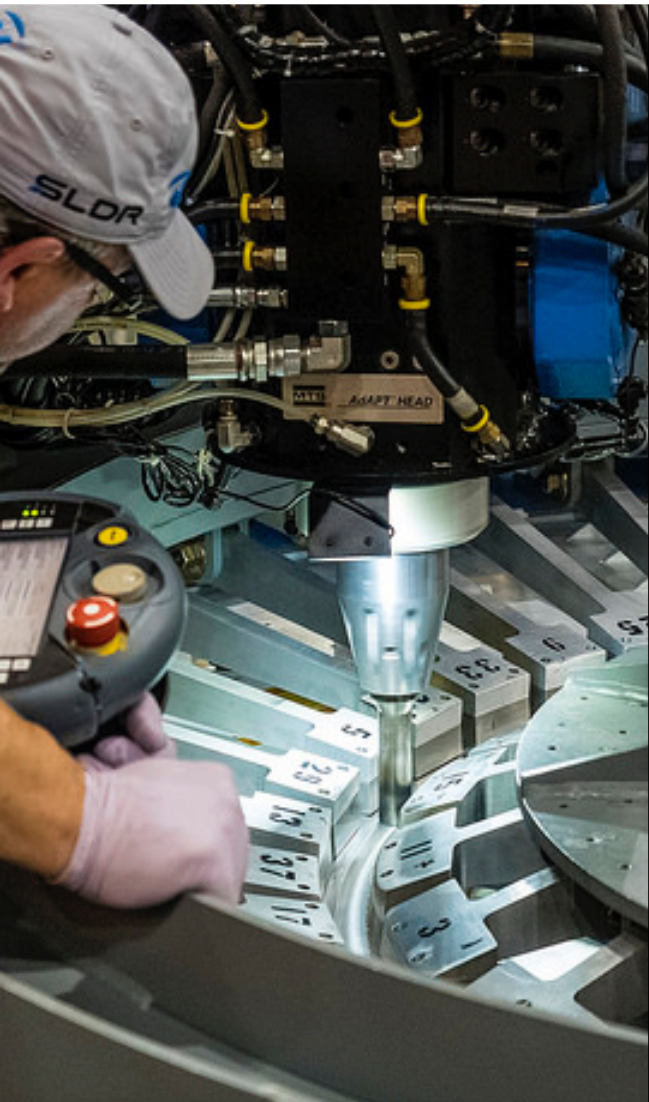


# SpaceX-8 Mission Status

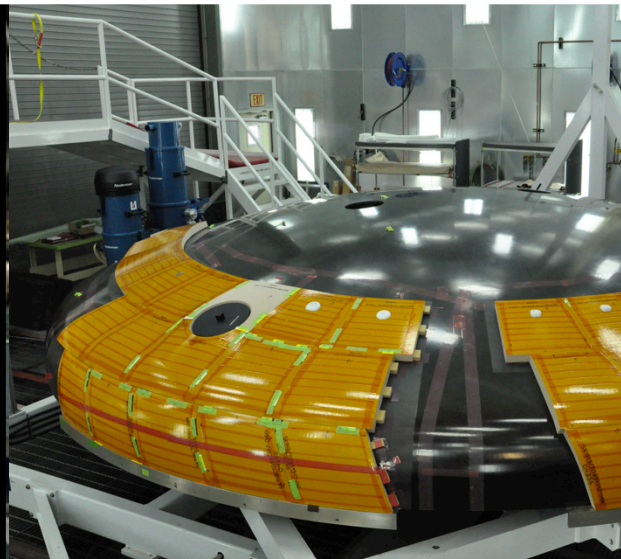


- **Mission Planning**
  - Cargo Integration Review (CIR) Part 1 completed on 5/28/15 with Part 2 planned for Oct
  - Safety Review Panel (SRP) Phase 3 review is planned to be complete by 10/7/15
  - Post Qualification Review (PQR) is planned for Nov
  - Stage Operations Readiness Review (SORR) is planned for Dec
- **Pressurized Cargo**
  - 1 Animal Enclosure Module-Transporter (AEM-T), 3 Polars (2 powered), and a NORS O2 Tank
  - Planned Upmass: 3,810 pounds. Planned Return: 4,100 pounds
- **External Cargo**
  - Bigelow Expandable Activity Module (BEAM) arrived at KSC on 7/23/15 and SpX is beginning integration. BEAM installed in trunk
    - Working Dragon trunk latch issue
      - Piston rod in latch failed
- **Dragon Status**
  - Capsule and trunk stacking for integrated checkouts at Hawthorne was completed on 7/27/15
  - Final hatch blowdown and Acceptance Test Procedure (ATP) was completed on 8/25/15
  - Vehicle in the Loop (VITL) and polarity testing was completed on 8/31/15
  - Trunk and capsule shipped to KSC
- **Falcon 9 Status**
  - SpX-8 will be first CRS Falcon flight with full thrust capability (2<sup>nd</sup> or 3<sup>rd</sup> Falcon flight with full thrust)
  - Interstage in final assembly preparing for Stage 1 mate
  - M1D qualification completion is planned for Oct with MVac qualification planned for Nov
  - Stage 1 and 2 are planned to ship to TX for ATP

# Orion Accomplishments



First weld of Orion Exploration Mission-1 crew module pressure vessel Michoud Assembly Facility



A manufacturing development unit of Orion's heat shield is being built at Lockheed Martin's facility in Denver



Orion's most challenging parachute drop test to date a success in August in Yuma, Arizona



Pieces for the Orion spacecraft that will fly on EM-1 being prepared for welding at MAF

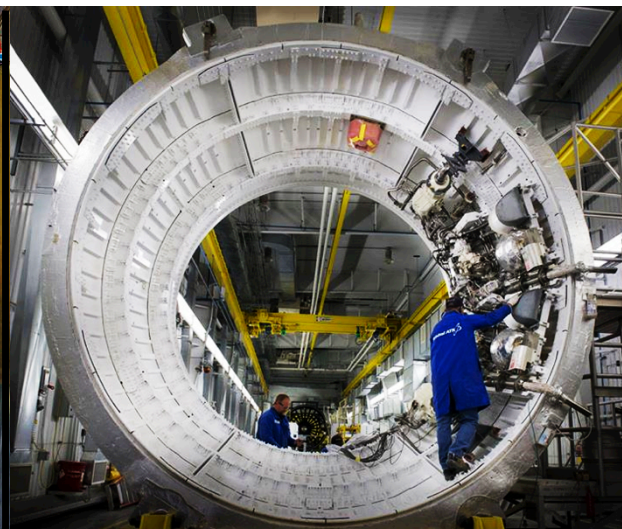


The Orion Crew Module Adapter simulator arrives at Plum Brook Station Space Power Facility in Sandusky, Ohio

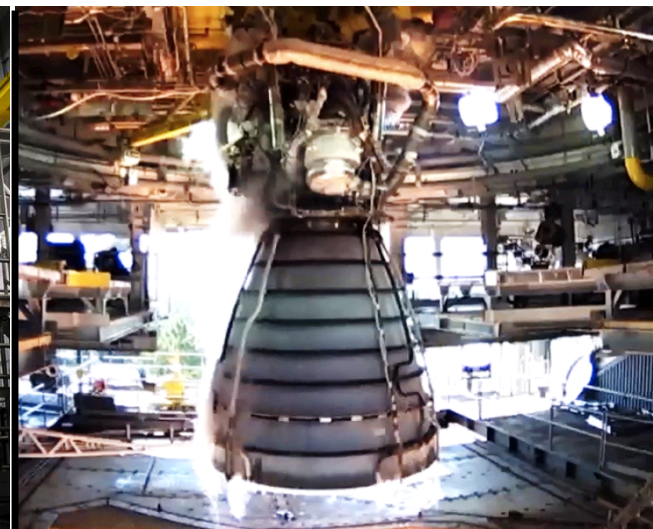
# Space Launch System Accomplishments



Launch Vehicle Stage Adapter  
Test Article fabrication



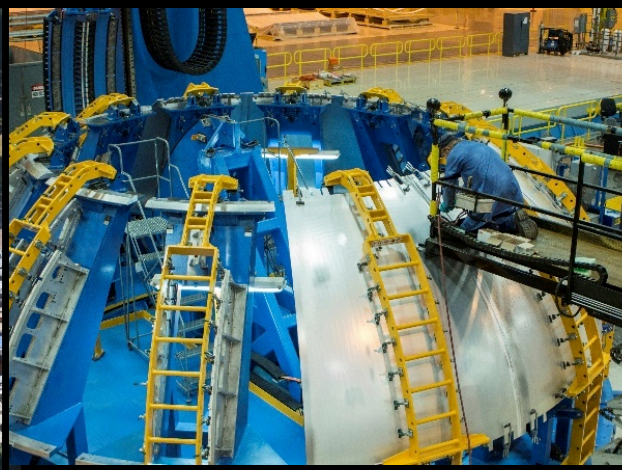
Booster Test Article in progress for  
second qualification firing



RS-25 engine test conducted  
at Stennis Space Center



Steel towers rising for new SLS test  
stand at Marshall Space Flight Ctr.



SLS Core Stage hydrogen tank  
progress, Michoud Assembly Facility



Pegasus barge completed, in  
dock at Stennis Space Center

# Ground Systems Development & Operations Accomplishments



Platform H is the newest platform to be delivered to the VAB at KSC



Simulation tests in Firing Room 4 at the Launch Control Complex at KSC



ICPS Umbilical arm guided into vertical position at the LETF at KSC

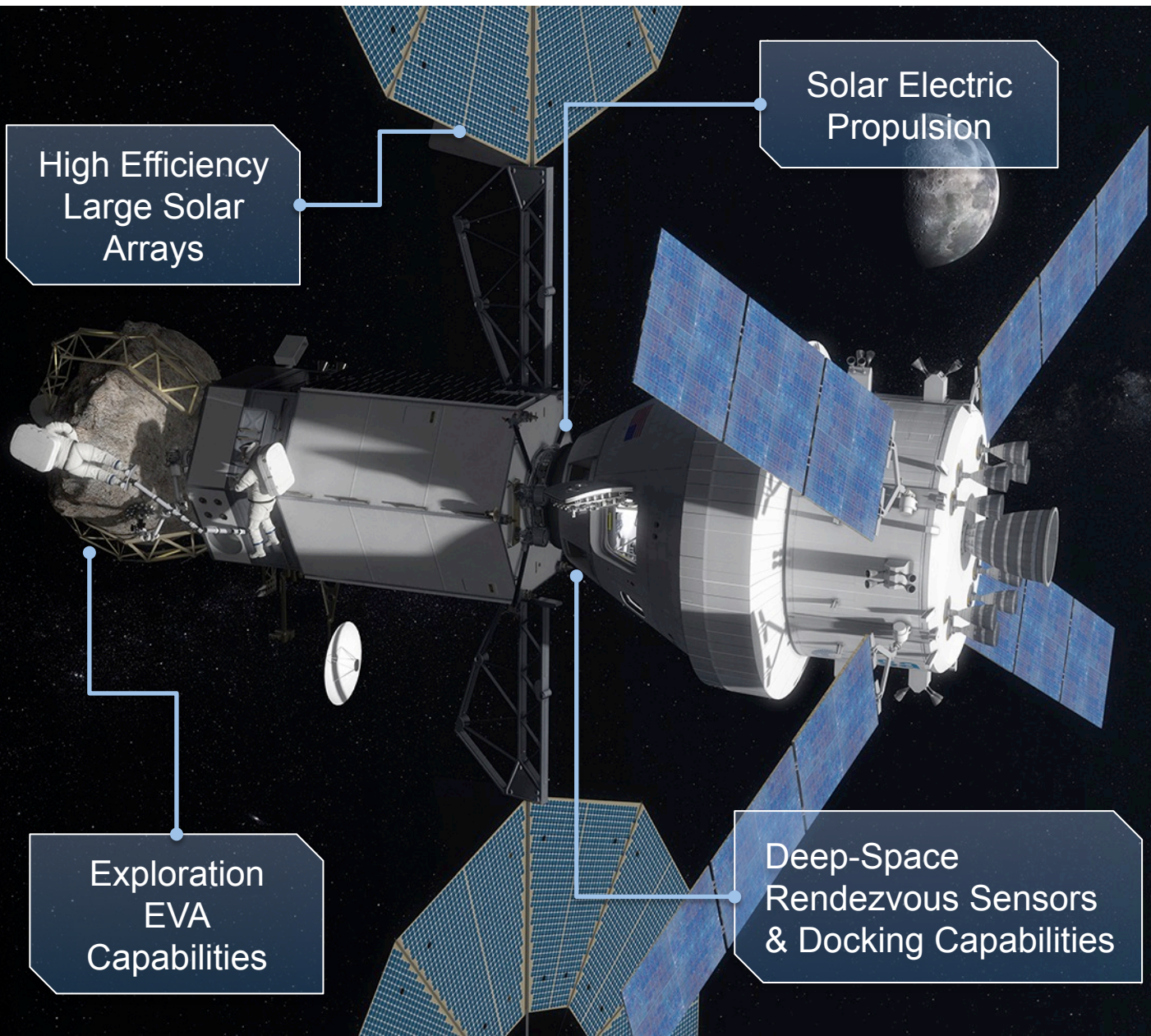


Ribbon cutting for Small Class Vehicle Launch Pad 39C



Modifications complete to Mobile Launcher base and tower structure at KSC

# ARM: An Early Mission in the Proving Ground of Cis-Lunar Space



## IN-SPACE POWER & PROPULSION:

- High efficiency 40kW SEP extensible to Mars cargo missions
- Power enhancements feed forward to deep-space habitats and transit vehicles

## EXTRAVEHICULAR ACTIVITIES:

- Two in-space EVAs of four hours each
- Primary Life Support System design accommodates Mars
- Sample selection, collection, containment, and return

## TRANSPORTATION & OPERATIONS:

- Capture and control of non-cooperative objects
- Common rendezvous sensors and docking systems for deep space
- Cis-lunar operations are proving ground for deep space operations, trajectory, and navigation

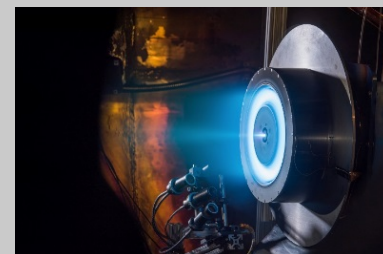
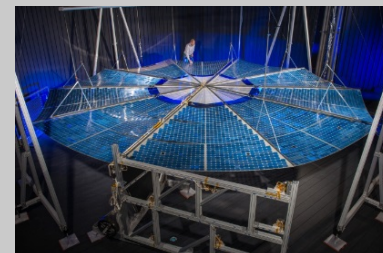
- **Acquisition Strategy for the Asteroid Redirect Robotic Mission (ARRM) completed in August**
  - NASA will significantly leverage commercially available spacecraft bus capabilities in an acquisition of a ~5t propellant capacity vehicle
  - More synergy in future commercial industrial base and other potential near term applications with this vehicle class.
  - Leveraging current commercially available spacecraft bus capabilities and future plans can decrease cost risk for NASA's Asteroid Redirect Mission
- **NASA chartered the ARM Formulation Assessment and Support Team to provide timely inputs for mission requirements formulation in support of the ARRM Requirements Closure Technical Interchange Meeting (TIM) planned for December 15-16, 2015**
  - Assist in mission requirements development
  - Develop an initial list of potential mission investigations,
  - Provide input on potential hosted payloads and partnerships.
  - 18 members, largely comprising universities and research institute/laboratories
- **2008EV5 is still the reference target asteroid**

# ARM-Major Risk Reduction Activities Completed by Glenn Research Center for STMD

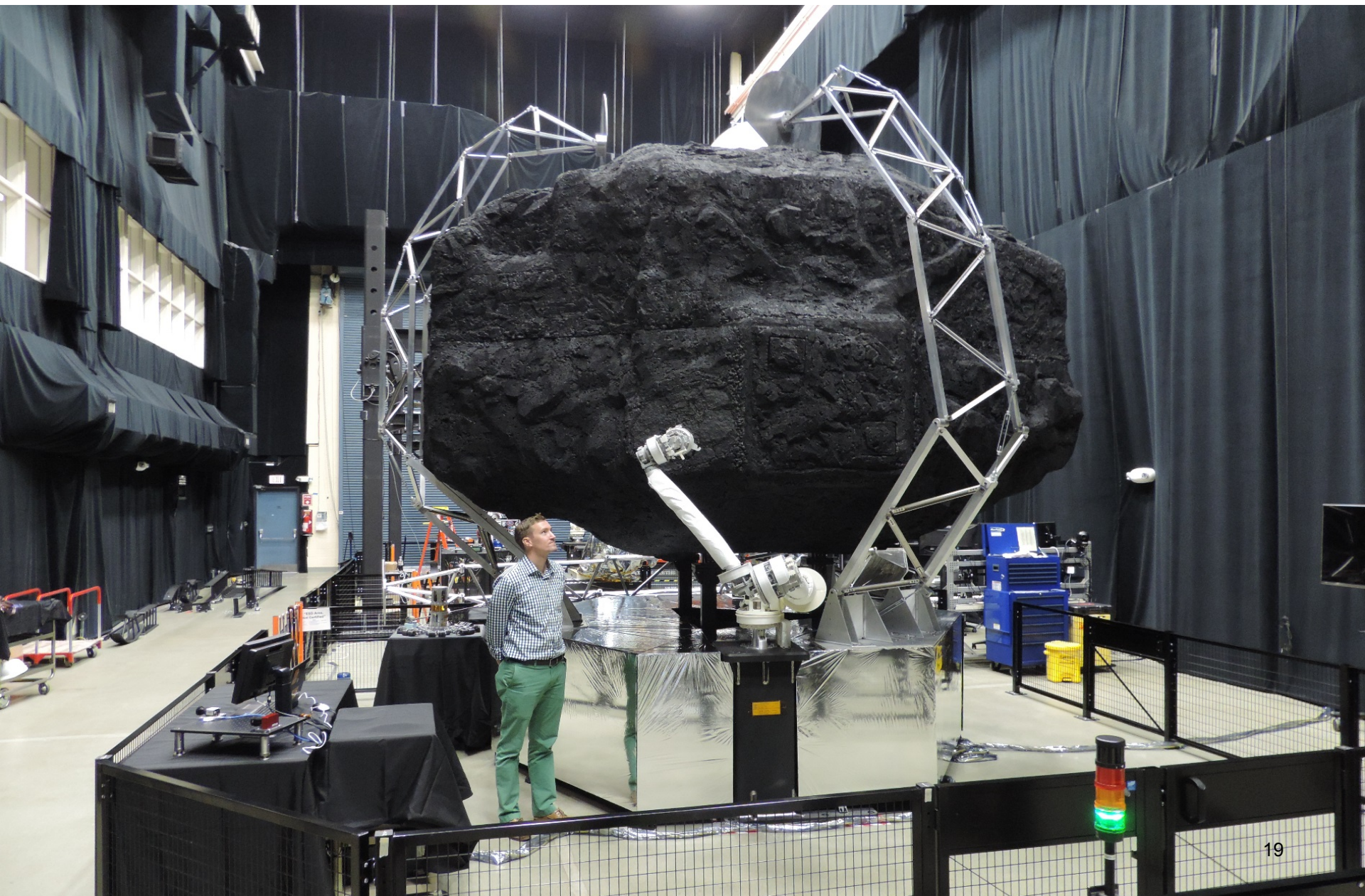


- **Solar Array Development Contracts Fully Successful**
  - MegaFlex Engineering Development Unit (ATK)
  - ROSA Engineering Development Unit (DSS)
  - Both arrays achieved all SOA-related goals including:
    - 4x stowed volume efficiency (40 kW/m<sup>3</sup> BOL)
    - 20x deployed strength (0.1 g)
    - 4x rad tolerance ( $2 \times 10^{15}$  1MeV e/cm<sup>2</sup>)
    - 1.7x power/mass (100 W/kg EOL)
  - SSL and DSS partnered on commercial ROSA (12.5 kW)
- **Technology Development Thruster and PPU Tests at NASA GRC**
  - Confirmed thruster magnetic shielding (enables long-life operation)
  - Power Processing Unit vacuum tests successfully completed
  - Conducted 12.5 kW thruster integrated tests with 300-V and 120-V PPUs

Demonstrated full performance compatibility between thruster and PPUs



# ARM-Capture System Prototyping/Testing at Goddard Space Flight Center



# ARM- relative Navigation Subsystem (RNS)



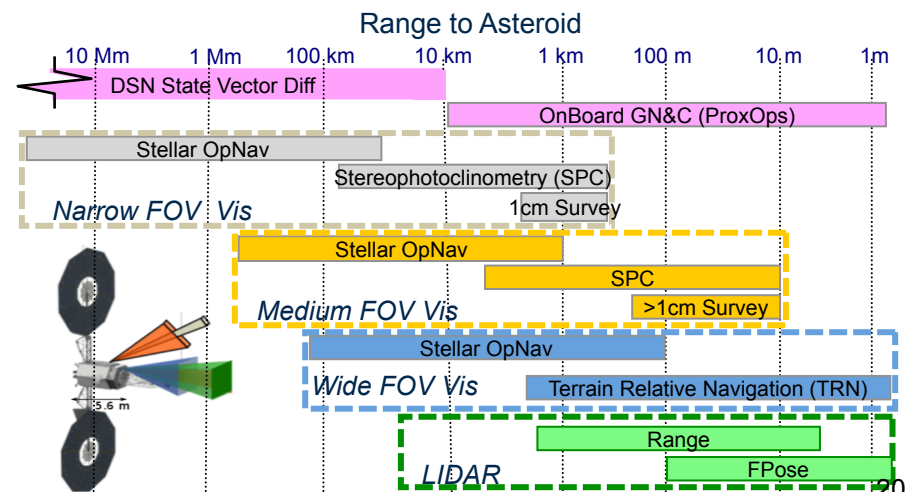
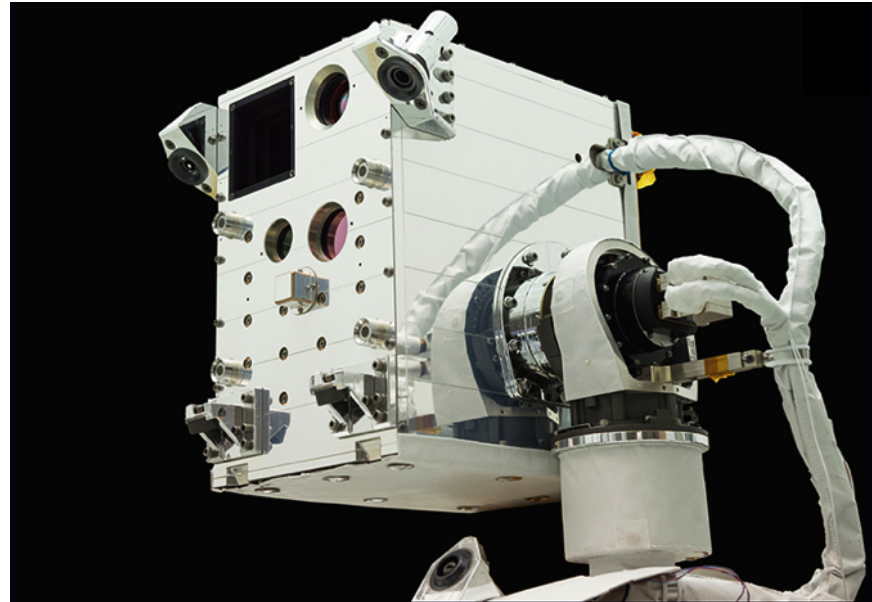
## Subsystem overview

- Ground processing: ~1cm res. map of boulder site
- Onboard processing: precision landing over boulder
- Fault tolerant sensors: visible and 3D Lidar
- Terrain-relative navigation algorithms hosted on hybrid HW/SW compute platform

## Technology Update

- Sensors will meet NASA Common AR&D Sensor spec (working towards draft specification release in FY16)
- Raven AR&D testbed will launch to ISS in summer 2016

Raven AR&D testbed (will launch to ISS in 2016)



# ARM-Contact and Restraint Subsystem (CRS)

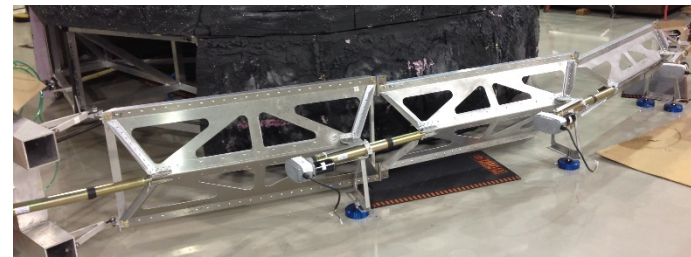
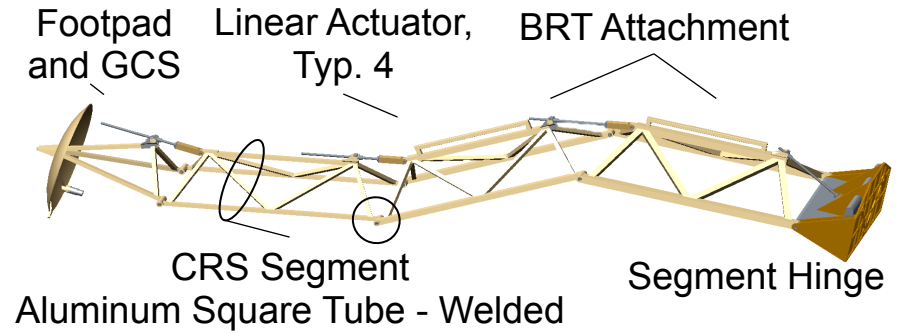


## Subsystem Overview

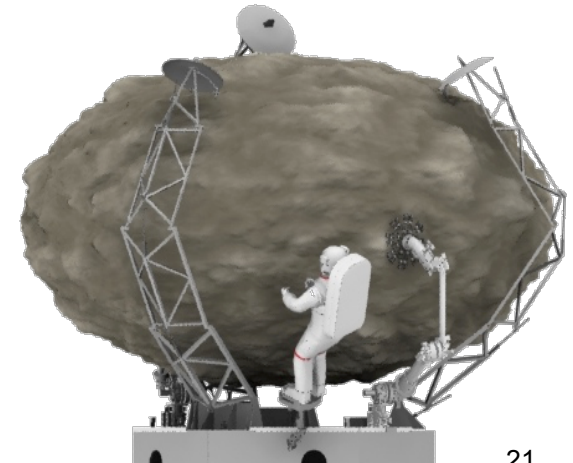
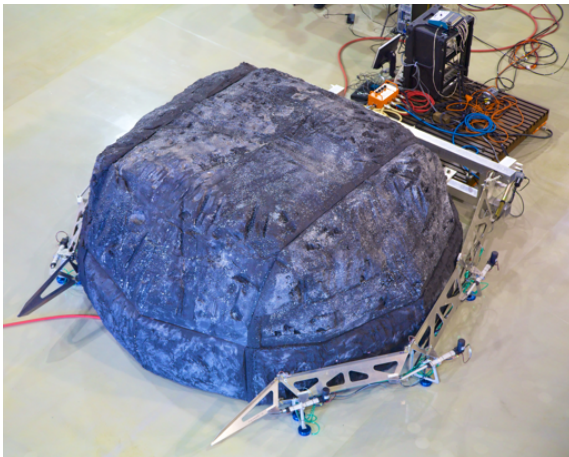
- Performs touchdown, ascent, and boulder restraint
- Three 4-DOF ~5 meter long truss legs with integrated linear actuators
- Footpads with accommodation for Geological Context Sampler (GCS)
- Designed to accommodate crew translation

## Technology Update

- Full scale welded metal prototype delivered
- Flat-floor testing of landing, extraction, and ascent underway



Prototype full-scale flat floor CRS limb

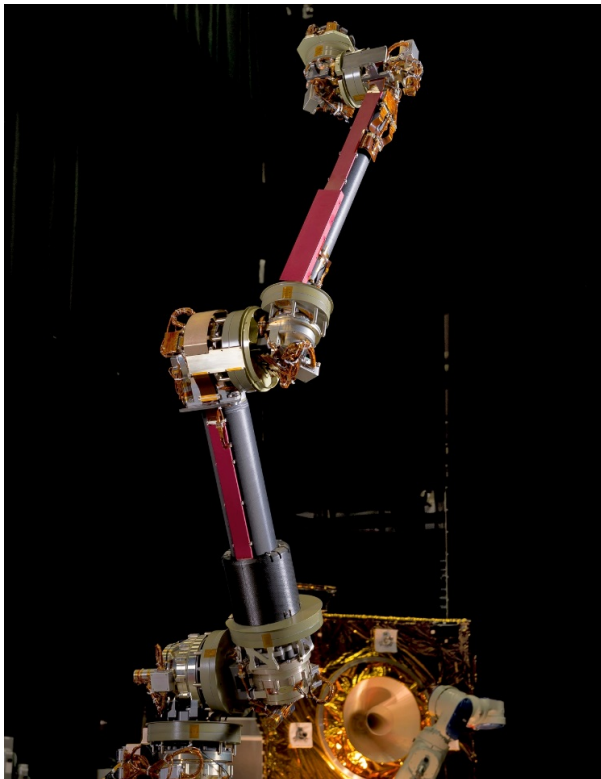


# ARM-Robot Subsystem



## Subsystem Overview

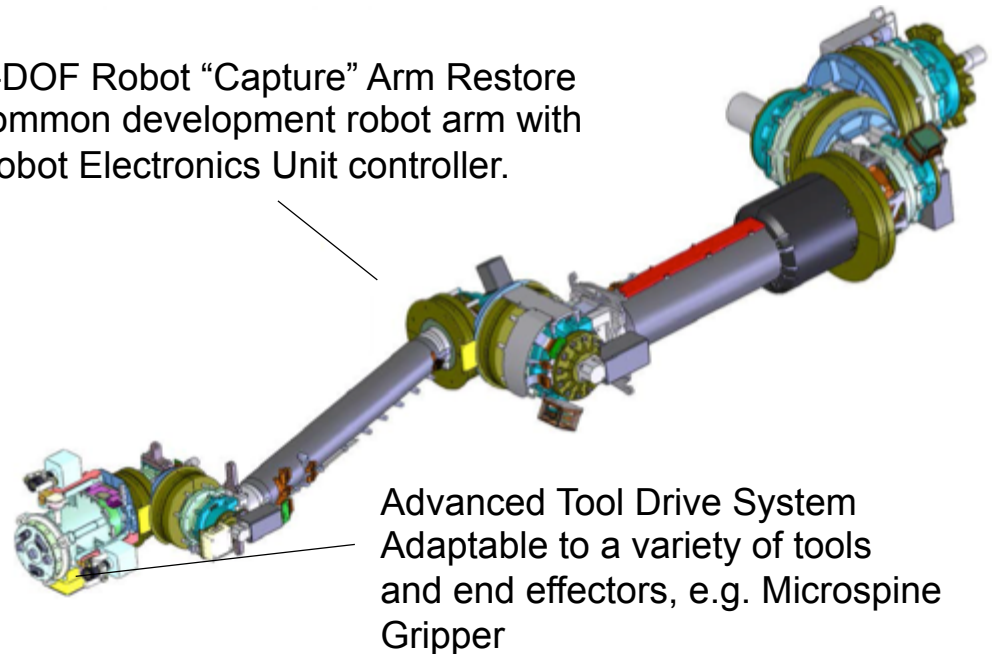
- 7-Degree-of-Freedom (DOF) robot arm with supporting electronics
- Advanced Tool Drive System (ATDS) at end of robot arm supports use and change out of multiple tools during the mission



## Technology Update

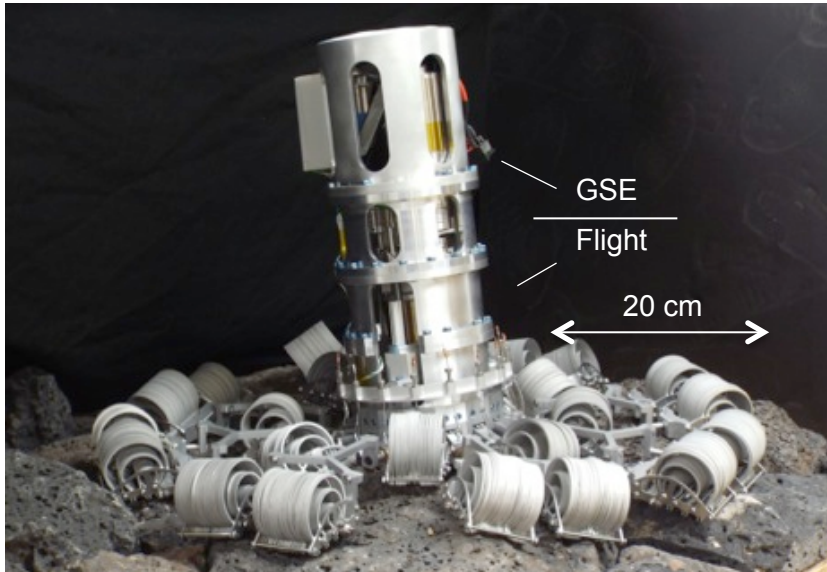
- Satellite Servicing development arm (EDU) delivered to GSFC June 2015
- ATDS engineering unit in final integration
- Based on ARRM mission requirements, updated arm common spec to include accommodation for locking brakes to increase load capability

7-DOF Robot “Capture” Arm Restore common development robot arm with Robot Electronics Unit controller.



Advanced Tool Drive System Adaptable to a variety of tools and end effectors, e.g. Microspine Gripper

# ARM-Robot Subsystem - Microspine Gripper



Microspine Gripper

## Tool Overview

- Uses ~2000 independent hooks to opportunistically grip the surface
- Fast release capability
- Integrated rotary-percussive anchoring drill augments Microspine grip capability
  - Design update from risk reduction

## Technology Update

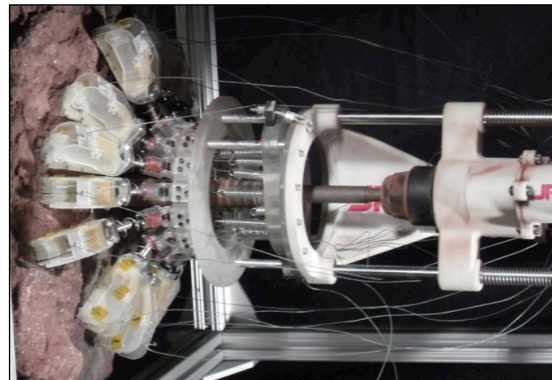
- Updated design of gripper, drill, drivetrain, and anchor
- Prototypes completed and tested with surrogate asteroid material



Carriage (1 of 24)



Microspine  
(1 of 652)



Microspine 1.0 and Integrated  
Drill



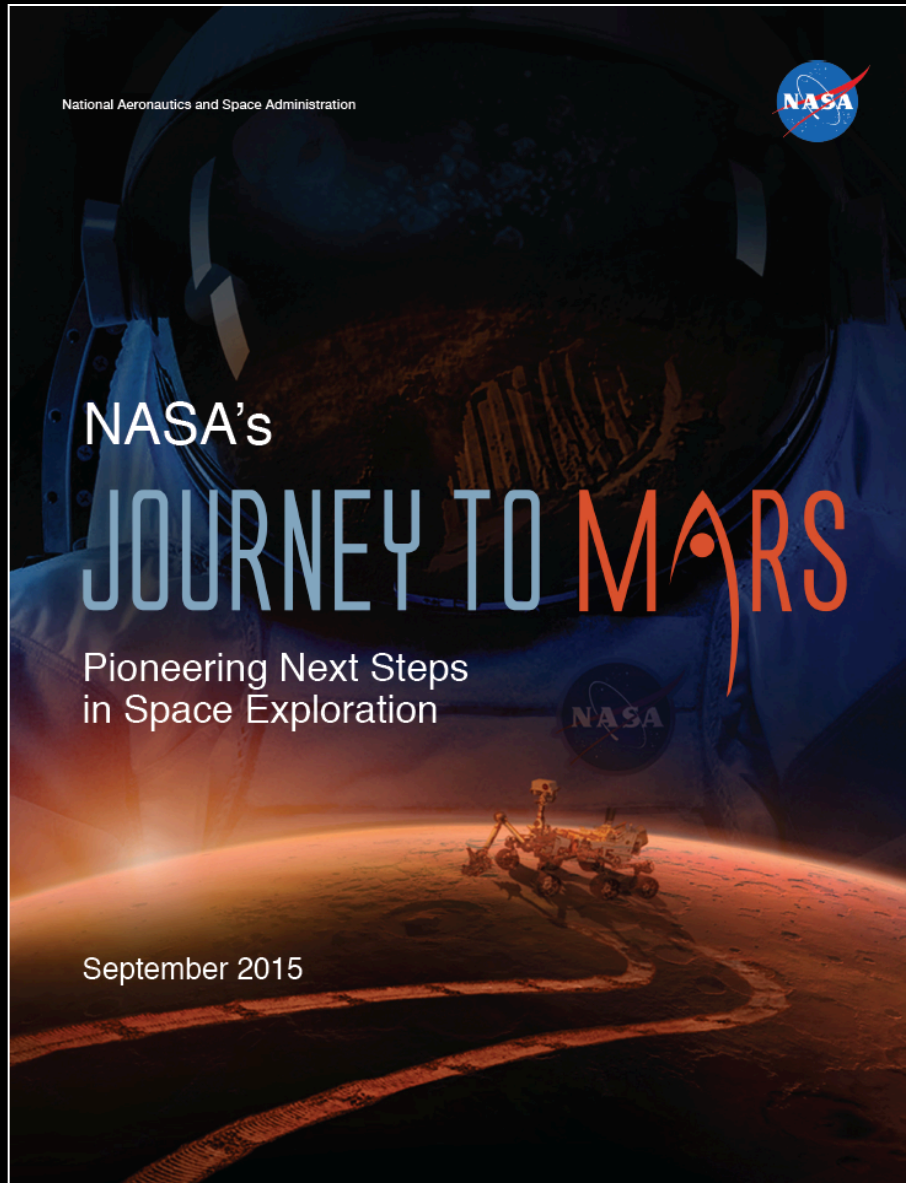
Anchor Bit  
Prototype Cutaway

# Proving Ground Objectives

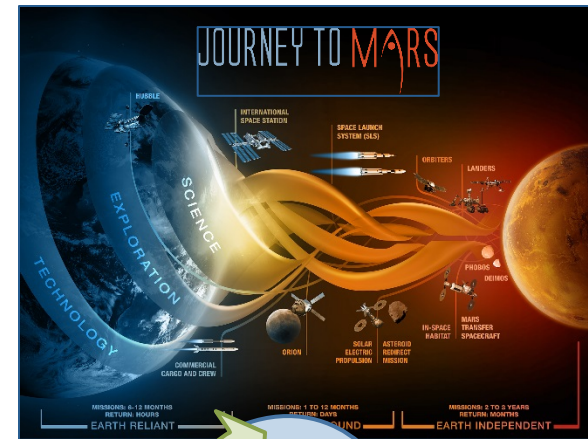


| Category         | Title                                   | Objective   |
|------------------|---|---|
| Transportation   | Crew Transportation                     | Provide ability to transport at least four crew to cislunar space   |
| Transportation   | Heavy Launch Capability                 | Provide beyond low-Earth orbit launch capabilities to include crew, co-manifested payloads, and large cargo   |
| Transportation   | In-Space Propulsion                     | Provide in-space propulsion capabilities to send crew and cargo on Mars-class mission durations and distances   |
| Transportation   | Deep Space Navigation and Communication | Provide and validate cislunar and Mars system navigation and communication  |
| Working in Space | Science                                 | Enable science community objectives   |
| Working in Space | Deep Space Operations                   | <p>Provide deep-space operations capabilities</p> <ul style="list-style-type: none"> <li>• EVA</li> <li>• Staging</li> <li>• Logistics</li> <li>• Human-robotic integration</li> <li>• Autonomous operations</li> </ul> |
| Working in space | <i>In-situ</i> Resource Utilization     | Understand the nature and distribution of volatiles and extraction techniques and decide on their potential use in human exploration architecture.  |
| Staying Healthy  | Deep Space Habitation                   | Provide beyond low-Earth orbit habitation systems, sufficient to support at least four crew on Mars-class mission durations and dormancy  |
| Staying Healthy  | Crew Health                             | Validate crew health, performance and mitigation protocols for Mars-class missions  |

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# Design Reference Missions vs Design Philosophy



## Body of Previous Architectures, Design Reference Missions, Emerging Studies and New Discoveries

- Internal NASA and other Government
- International Partners
- Commercial and Industrial
- Academic
- Technology developments
- Science discoveries

## Evolvable Mars Campaign

- An ongoing series of architectural trade analyses that we are currently executing to define the capabilities and elements needed for a sustainable human presence on Mars
- Builds off of previous studies and ongoing assessments
- Provides clear linkage of current investments (SLS, Orion, etc.) to future capability needs

# EMC Questions/Work Groups



- A. How do we pioneer an extended human presence on Mars that is Earth independent?**
- B. What are the objectives, engineering, and operational considerations that drive Mars surface landing sites?**
- C. What sequence(s) of missions do we think can meet our goals and constraints?**
- D. Is a reusable Mars transportation system viable?**
- E. Can ARV derived SEP support Mars cargo delivery requirements?**
- F. How can we maximize commonality across Mars ascent, Mars vicinity taxi, exploration vehicle and initial deep-space habitation component?**
- G. What are the required capability investments for the EMC over the next five years?**
- H. What is the appropriate habitation system?**
- I. Is Phobos a viable human target?**
- J. What are potential Mars surface pathfinder concepts?**
- K. What capabilities are needed to enable elements to survive long dormancy periods in space?**
- L. What communications capabilities are needed?**
- M. Can humans survive 1000 days in deep space?**
- N. Can there be synergy between landers for multiple planetary surfaces?**

# FY2016 EMC Questions/Work Groups (A-F)



## **A. How do we pioneer an extended human presence on Mars that is Earth independent?**

- What are potential build-up scenarios for In-situ Resource Utilization to reduce logistics chain and increase sustainability

## **B. What are the objectives, engineering, and operational considerations that drive Mars surface landing sites?**

- Mars exploration and science objectives for short and long stay missions
- Landing Site Requirements and Constraints

## **C. What sequence(s) of missions do we think can meet our goals and constraints?**

- Will campaign concepts satisfy the strategic principles?

## **D. Is a reusable Mars transportation system viable?**

- Can an evolved ARV provide required function of in-space transportation to transport to Mars vicinity and be reused for multiple missions?
- Reuse of habitat - Can a 1000 day habitat be refurbished and reused for multiple missions?

## **E. Can ARV derived SEP support Mars cargo delivery requirements?**

- Can an evolved ARV provide required function of in-space transportation to transport cargo required to Mars vicinity and return safely (41mt roundtrip)?

## **F. How can we maximize commonality across Mars ascent, Mars vicinity taxi, exploration vehicle and initial deep-space habitation component?**

- Can a minimal MAV be used for Mars Taxi, Mars Moon Exploration vehicle, & surface rover?
- Trade study of propulsion system (LOx/CH4 and Hypergols)

# FY2016 EMC Questions/Work Groups (G-N)



## **G. What are the required capability investments for the EMC over the next five years?**

- What are the capabilities (and their respective development roadmaps) that need to be developed prior to sending crew to Mars vicinity?
  - What are the capabilities and associated Flight Test Objectives that need to be tested on ISS?
  - What are the capabilities and associated Flight Test Objectives that need to be tested in cis-lunar space?

## **H. What is the appropriate habitation system?**

- Can a 1000 day habitat fully loaded with consumables be developed that is less than 41mt?
- Identify evolvability of habitation systems into Mars architecture to include identification of functional requirements.

## **I. Is Phobos a viable human target?**

- Trade study of exploring Phobos and Deimos via teleoperations from an orbital mission and the addition of an short duration excursion mission?
- What are potential options for sample acquisition and handling

## **J. What are potential Mars surface pathfinder concepts?**

- Working with SMD and OCT, what are potential orbital and lander pathfinder concepts and their associated benefit?
- Benefits of Lunar rover demonstrations

## **K. What capabilities are needed to enable elements to survive long dormancy periods in space?**

## **L. What communications capabilities are needed?**

- What are communication needs for proving ground missions and Mars vicinity missions

## **M. Can humans survive 1000 days in deep space?**

- What are risk mitigation systems and operational approaches to keep crew safe for Mars vicinity missions

## **N. Can there be synergy between landers for multiple planetary surfaces?**

- Human class Mars lander
  - Can surface exploration be accomplished with an 5mt, 8mt or 20mt lander?

# Proving Ground Capability Evolution

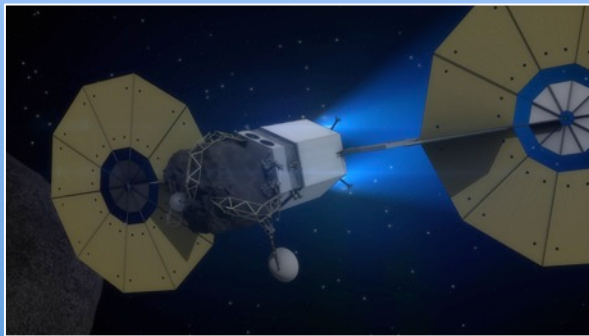
Note: Concepts shown are notional



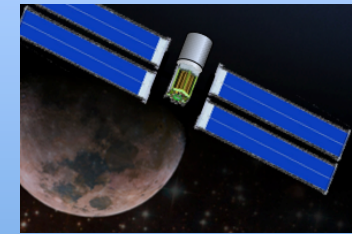
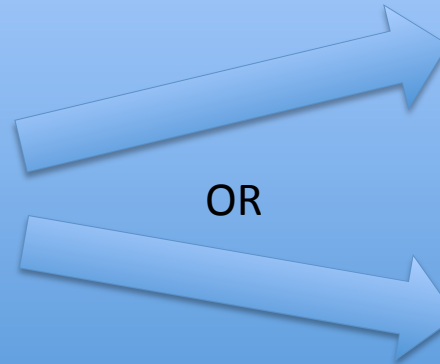
## Initial Phase of Proving Ground

## End of Proving Ground

### In-Space Transportation Evolution

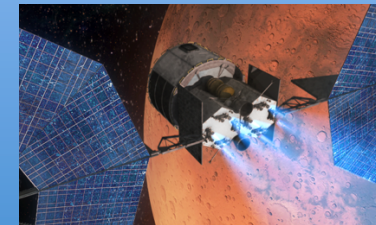


ARM SEP Development



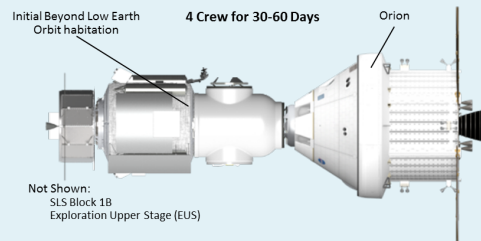
Split SEP /  
Chemical

### Mars-Class Mission SEP Validation

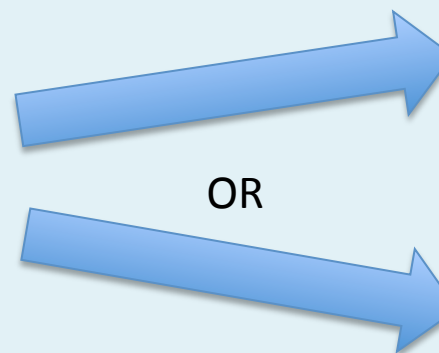


Hybrid SEP /  
Chemical

### Long Duration Habitation Evolution

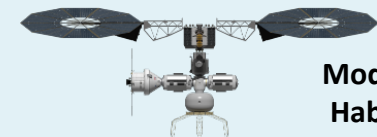


Initial Beyond Low Earth  
Orbit Habitation Development



Monolithic  
Habitat

### Mars-Class Mission Habitation Validation

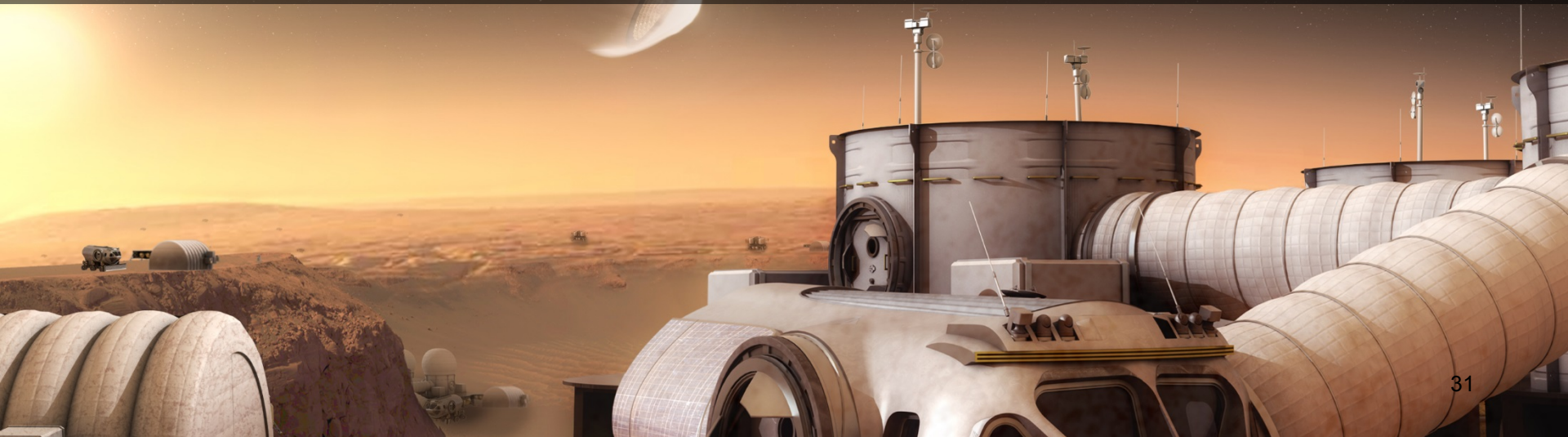


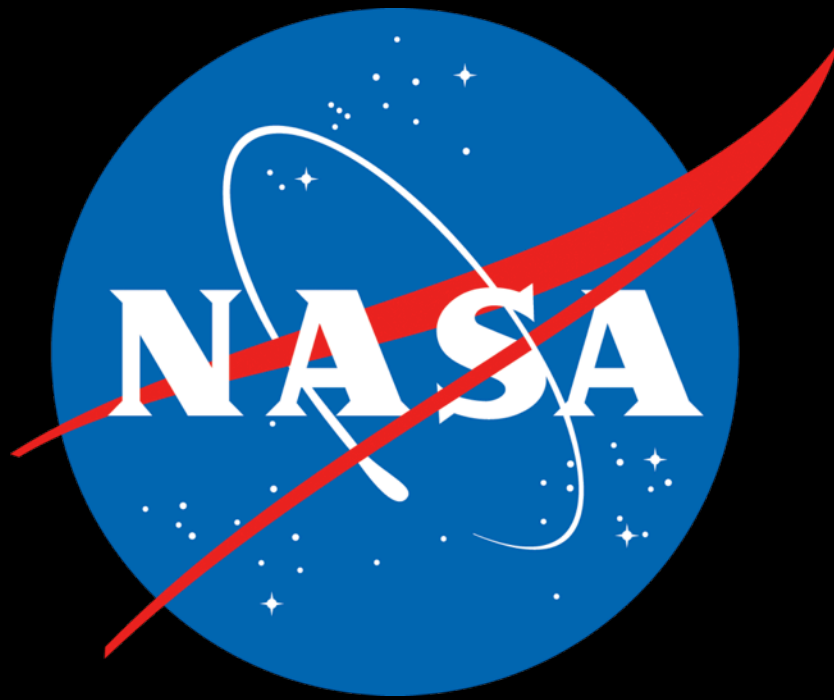
Modular  
Habitat

# Summary



- The Journey to Mars requires a resilient architecture that can embrace new technologies, new international/commercial partners, and identify agency investment choices to be made in the near, mid and long term.
- The Evolvable Mars Campaign:
  - Informs the agency choices by providing technical information from a cross agency, end-to-end integrated analysis
  - Needs to continue to develop linkages to the agency decision making and capability investment processes
- Regardless of which path is ultimately selected, there are a set of common capabilities required to be developed by NASA and its partners over the next 10 years





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